IMPLEMENTING A PAVEMENT MANAGEMENT SYSTEM IN THE PHILIPPINES USING THE HIGHWAY DEVELOPMENT AND MANAGEMENT (HDM-4) MODEL

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ABSTRACT

The Department of Public Works and Highways (DPWH) in the Philippines is responsible for the management and maintenance of about 29,600 km of national roads. At present, there is a considerable competition for relatively scarce resources to meet the growing demands for road maintenance and rehabilitation of this road network. Hence, as part of the DPWH decision to upgrade some of its current systems and procedures to ensure that expenditure priorities are established by rational methods, which maximize benefits from investments on the road network, a Pavement Management System (PMS) has been developed and is now being implemented using the Highway Development and Management model, HDM-4, as the economic analytical tool to develop both long term (strategic) plans and medium term multi-year works programmes for the management of this road network.

The Philippine national road network comprises of pavements with asphalt and cement concrete surfacing as well as lengths of roads that are unsealed. These sections of road are of varying condition and age and therefore, the challenge is to identify the appropriate strategy for preserving or maintaining them over the long term. The PMS through the HDM-4 will provide the impetus for a greater emphasis on the preservation of these road pavements. It is based on the use of economic rational to determine the most appropriate maintenance budget for asset preservation given the financial constraints. It will enable quality decision making on a life cycle basis since this tool will provide an insight into the impact of policies and decisions on pavement performance, and thus, can provide a means to diminish political intervention.

This paper describes the process of implementing and adopting a Pavement Management System which supports needs analysis, multi-year programming and annual budgeting for the preservation of road pavements on the national road network in the Philippines, customized to local conditions.

1. INTRODUCTION

The road network in the Philippines is an integral component of the country's transportation infrastructure of which the Department of Public Works and Highways (DPWH) is a major provider, responsible for national roads. DPWH's primary goal is to develop and maintain a highway system through the national arterial road network that could perform its function efficiently and expeditiously at the lowest tenable user-cost, affording high quality paved roads with safe and environmentally satisfactory features.

To develop further its institutional capacity, the DPWH took the decision to upgrade some of its current systems and procedures. At present, it is now implementing a new planning process that employs these new planning systems and procedures. One of these systems is the Pavement Management System (PMS) which has been developed to support the planning, programming and implementation of road development and preservation taking into account the optimized use of scarce resources by rational methods which will maximize the benefits from expenditures on the road network.

The PMS uses the Highway Development and Management model, HDM-4, as the economic analytical tool to develop both long term (strategic) plans and medium term multi-year works programmes for the management of the road network.

The PMS was created and adapted for the Philippines national road network as a highway planning tool and procedure that will develop forecasts and allocations of road development and preservation expenditure programs, and which will also provide the basis for prioritization of projects and optimization against performance and economic returns.

2.0 PAVEMENT MANAGEMENT SYSTEM FOR DPWH

The pavement management in its broadest sense includes all the activities involved in planning & programming, design, construction, maintenance, and rehabilitation of the pavement portion of the road works program. The Pavement Management System (PMS) on the other hand is a set of tools and procedures that assist decision makers in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time. The inputs to pavement management tools are quality data and reliable information. These are essential if the outputs of the PMS are to be used with confidence for planning purposes.

The pavement management process starts from the planning stage of an asset, through its physical life and continues to the stage of decommissioning. Each road section of the Philippine national road network comprises an asset for the purposes of this process and therefore each section needs to be managed in such a way that performance and maintenance costs are balanced to provide optimal outcomes.

At present the road network comprises many sections of varying condition and age and therefore the challenge is to identify an appropriate strategy for maintaining them over the long term. To do so requires understanding the deterioration behavior of the pavements and forecasting the impact of this deterioration on road users.

The process therefore begins with defining the road asset in terms of pavement and geometric composition and collating data that relates to asset deterioration. Together these form the core of information on which forecasts will be made of deterioration. To manage this process in a systematic way a functional methodology is employed. This methodology is shown in Figure .

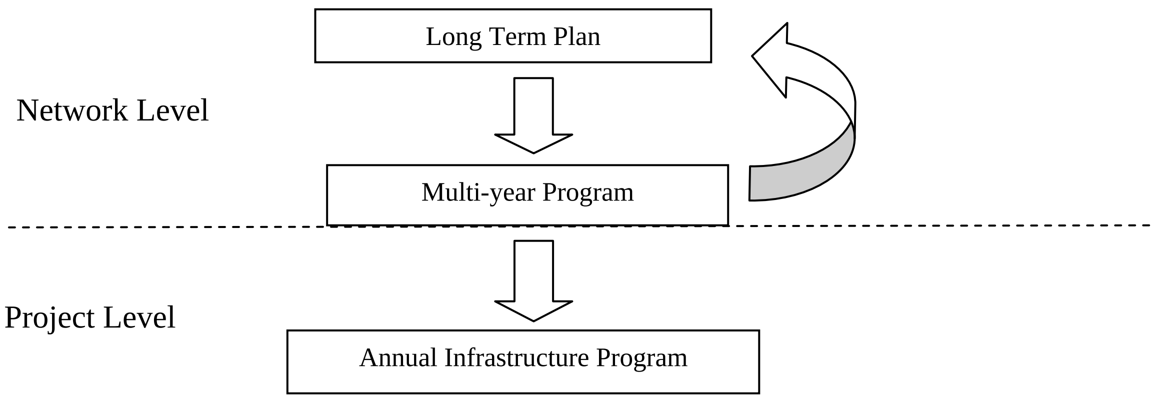

Figure 1. Pavement Management Levels

PMS can also be viewed in terms of two basic working levels:

- Network Level
- Project Level

PMS in network level is generally concerned with long term policy and target analysis, development of works programs for rehabilitation, maintenance or new pavement construction works within overall budget constraints. On the other hand, project level works comes “on stream” at the appropriate time schedule. The PMS Application based on HDM-4 is basically developed as network level planning and programming tool.

3.0 THE ROLE OF THE PMS IN THE NEW PLANNING PROCESS

A new network planning process was developed as part of improvements to the Department's institutional capacity. To facilitate the analytical needs of the new planning process, a pavement management system (PMS), customized to the Philippines, has been developed.

The existing process has evolved from a project oriented approach towards a planning and programming system based on aggregation of projects as formulated by various stakeholders. The system can be characterized as supply-driven rather than based on needs.

The new process focuses on an integrated and comprehensive planning and programming approach where all planning and programming units of DPWH work together following the DPWH vision, mission, goals and objectives. There are three phases that are of major importance in appreciating the nature of the changes in the way that the DPWH carries out planning and programming for the long term and medium term future that have been introduced:

- Asset preservation and network development are integrated during the early stages of the overall planning process.
- Actual road and bridge projects are identified, prioritized and costed at the later stages of the process, i.e. Multi-Year Programming.
- Planning interests both external and internal to DPWH are involved in the planning process at an earlier stage. NEDA is now actively involved in all the stages; Regional Development Councils (RDC) contribute to the development of future highway network scenarios; Regional and District offices and BOM play a part in developing the Long-term plan for the network.

3.1 Stages in the New Planning Process

The new planning process has four stages which can be summarized as follows:

- Perform Strategic Analysis
- Develop Highway Network Scenarios
- Develop Long-term Plan
- Prepare Multi-year Works Program

Of the four stages outlined above, the latter three stages are of particular relevance to the development of the PMS.

3.2 Long-term Plan

The Long-term plan is prepared for a 24-year period. The new planning process requires that it is updated every six years. It is done in two stages a) developing highway network scenarios which define long term needs, testing various alternative network scenarios and identifying appropriate targets and policies and b) preparing long-term plan which is related with implementation of policy decisions in the long-term. For both of these stages HDM-4 Strategy analysis is used.

Typical outputs from the Long-term plan would include:

- Forecasts of road network performance based on Key Performance Indicators (KPI) under varying levels of funding over 24 years (see Figure 2 and Figure).
- Optimal allocation of funds according to defined budget heads for each 6-year period over the 24 years (see Figure 4).
- Policy studies such as impact of changes to the axle load limit, pavement maintenance standards, sustainable road network size, and evaluation of pavement design standards, etc.

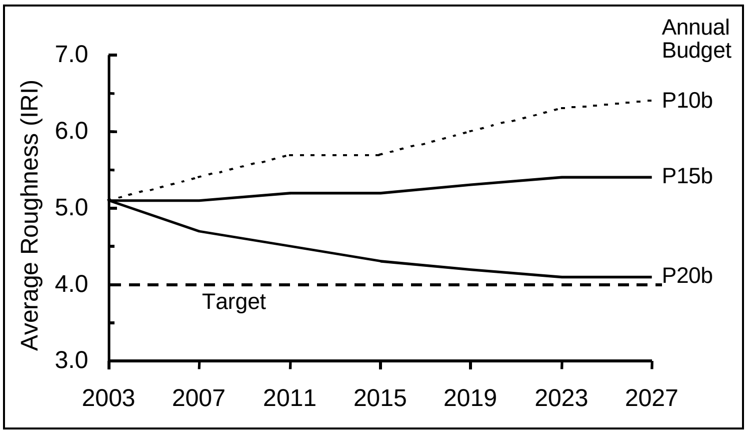

Figure 2. Effect of Funding Levels on Road Network Performance

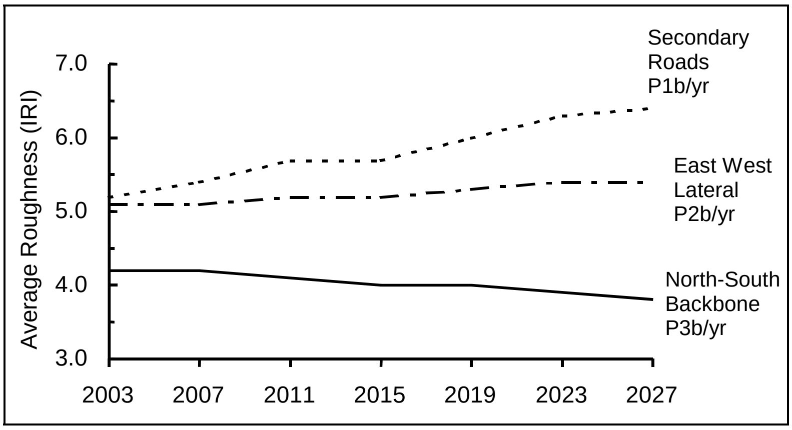

Figure 3. Effect of Budget Allocations on Sub-Network Performance

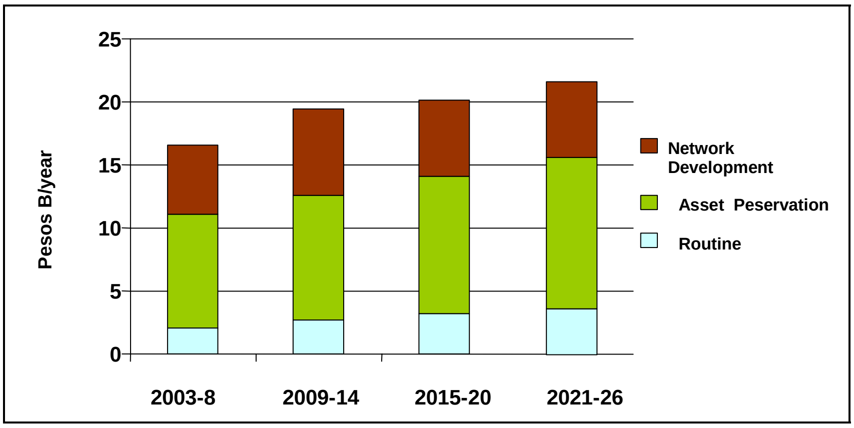

Figure 4.Optimal Budget Allocations to Sub-Heads

One of the main challenges in long term planning is the establishment of credible policies and targets. This is due to the uncertain nature of forecasting future requirements. Policies and targets should be based on network needs and availability of funding. The development of the PMS, which uses the Road & Bridge Information Application (RBIA) database and the HDM-4 as the analytical tool, will help to examine the economic feasibility of policies and targets that have been set.

3.3 Medium-term Plan

The medium term planning process provides an integrated assessment of needs over say a 6-year period. The focus of the Medium-term plan is the production of a Multi-year Works Program

(MWP), which satisfies the targets and policies of the Long-term plan. The MWP contributes in the preparation of the Medium Term Public Investment Program (MTPIP) and in the preparation of the Medium Term Philippine Development Plan (MTPDP).

The HDM-4 Program analysis is used to generate multi-year works program. Whereas in HDM-4 Strategy analysis, the road network is divided into a multi-dimensional network state matrix, in HDM-4 Program analysis individual planning road sections are analyzed. HDM-4 Program analysis is used to compare the life cycle costs predicted under various alternative maintenance, road improvement or development scenarios for each road section. For each alternative, a comparison is made of the 'without' (usually a do-minimum alternative such as routine maintenance only) case and each alternative to derive economic benefits for each alternative on each road section. An optimization procedure is then used by the HDM-4 to select the optimal maintenance or improvement standard for each road section within specified budget constraints. An optimized works program is generated for each budget scenario. An example of an optimized works program is illustrated in Table 1.

Priority Rank	**Road Section**	**Length (km)**	**Region**	**Type of Road Works**	**Construction Cost**	**Economic Benefit**
1	SS0002	20.5	I	25mm Reseal	P 4.5m	P 10.9m
2	SS0017	23.5	CAR	Overlay 40mm	P 4.2m	P 8.8m
3	SS0029	12.5	XII	Rehabilitate	P 4.6m	P 7.6m
4	SS0056	30.0	XI	Overlay 60mm	P 3.9m	P 6.7m
5	SS0021	36.2	VIII	150mm Regravelling	P 2.9m	P 5.4m
6	SS0045	32.1	II	13mm Reseal	P 2.5m	P 4.3m
7	SS0006	12.4	I	Overlay 50mm	P 2.3m	P 3.8m
8	SS0016	15.6	NCR	Upgrading Gravel to Sealed	P 2.0m	P 3.0m
9	SS0028	18.9	X	Upgrading – Earth to Gravel	P 1.9m	P 2.4m
10	SS0089	14.1	NCR	Replace Cracked Concrete Blocks	P 1.5m	P 1.8m
TOTAL					P 30.3m	P 54.7m

Table 1. HDM-4 Optimized Work Program

3.4 Multi Criteria Analysis

The optimized works program generated by HDM-4 analysis is used as a prioritized candidate project list under a specified budget scenario. Other qualitative and judgmental issues need to be assessed which go beyond the analytical abilities (primarily economic) of the PMS. Multi criteria analysis needs to be carried out to incorporate social and other issues in addition to the economic indicators. Hence the plans of other agencies need to be taken into account as well as current policy on foreign-assigned projects vis-à-vis local funded projects. Multi criteria analysis is used in prioritizing candidate projects in terms of project preparedness, importance of the overall network and response to Government's economic and social development policies.

In HDM-4 Program analysis, the derived timing and type of maintenance treatment may differ as a result of changes made to the level of budget specified in the analysis. For example, if a maintenance option on a road section is not carried out in a specific year because of budget constraints, it may no longer be economically feasible to carry out that maintenance activity in subsequent years. This may be due to reasons such as the condition of the section has further deteriorated to make the specified maintenance activity unviable (and other maintenance alternatives specified for that section feasible), or maintenance of other sections continue to have higher priority within the budget constraint. It is important to appreciate that the optimized works program generated by the HDM-4 analysis may differ based on the funding level. Hence, one of the main goals of the Medium-term plan is to establish funding levels that will satisfy the policies and targets, such as network performance indicators, and are sustainable in the long term.

3.5 Annual Works Program

HDM-4 Program analysis should be carried out annually to update the Multi-year Works Program based on the latest update of traffic and road condition information. Also it is important to take into account the maintenance and improvements activities that have actually been carried out in the previous year.

The sections included in the first year of the HDM-4 generated optimized Multi-year Works Program are considered for the Annual program. It is essential to randomly verify the works predicted for the first two years actually matches with the field requirements. MYPS is used to carry out multi criteria analysis to finalize the Annual program which will be later divided into the Annual Infrastructure Program (AIP) and the Annual Works Program (AWP). This is shown in **오류! 참조 원본을 찾을 수 없습니다.**.

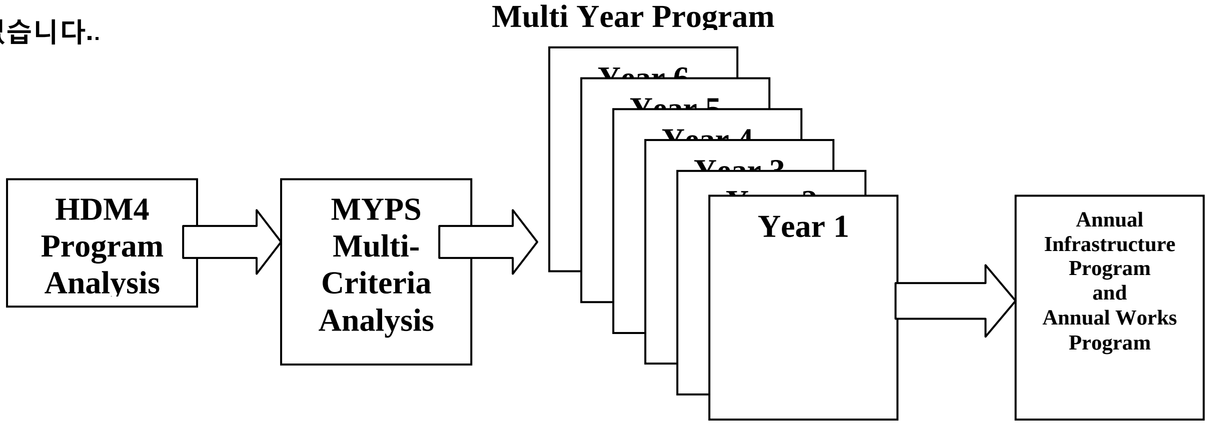

Figure 5. Medium-term Plan and Annual Program Preparation

4.0 BASIC COMPONENTS OF THE PMS

Using information available in RBIA and decision criteria (HDM-4 system configured for Philippines), the PMS can produce cost effective pavement asset preservation programs and policies. For this the PMS evaluates alternative strategies over a specified analysis period on the basis of predicted values of quantifiable pavement attributes subject to predetermined criteria and budget constraints. This will help to improve efficiency of decision making, expand the scope, provide feedback on consequences of decisions, facilitate coordination of activities within the agency, and ensure the consistency of decisions made for the complete national road network.

The PMS consists of the HDM-4 software and the HDM-4 Interface built in the RBIA. The RBIA which utilizes the facilities of the Confirm Software is used as the data repository for all network level data required for PMS. The HDM-4 Interface is used to prepare data required for the HDM-4 analysis. It enables further analysis of the data, including transformation of data into the units and format required for HDM-4 analyses. The HDM-4 Interface can also access the required data easily and various facilities available in the RBIA could be used for reporting and analysis purposes.

5.0 PAVEMENT MANAGEMENT PROCESS

The PMS process has several stages and these are the following:

- Data collection and management
- PMS Application configuration
- HDM-4 input data preparation
- HDM-4 Analysis
- Using HDM-4 outputs

5.1 Data Collection and Management

One of the most important parts of any PMS is the data. Credible output from PMS application is only possible with the availability of reliable data. The importance of data for maintenance planning cannot

be over emphasized. HDM-4 uses incremental models to predict the rate of pavement deterioration. This means that the prediction of next year's condition is a function of the current condition. Therefore, if the current condition is not a true reflection of the actual condition, it is guaranteed that the predicted conditions will be wrong. The cost of data collection increases with the accuracy level of the data and frequency of the collection. Hence for a sustainable PMS, it is required that data are collected at the required time intervals and that the collected data should be of the appropriate quality level. The main source of the data that will be used by the PMS is the RBIA database. The following types of data available in the RBIA database are used:

- Road Network Data (road inventory, road condition (roughness and visual condition data), pavement history, traffic (volume, composition and growth), project information (ongoing and committed projects)

5.2 PMS Application Configuration

There are two areas in the system that require configuration - the HDM-4 Workspace and the HDM-4 Interface.

- HDM-4 Configuration

HDM-4 is an economic road investment tool which has been developed to assist engineers and planners with road investment planning. Basically HDM-4 predicts the rates of deterioration of roads under alternative maintenance strategies and the road user costs for each alternative. It then conducts an economic analysis on the various alternatives and provides the user with economic indicators to assist with road investment planning.

In order for HDM-4 to predict appropriate rates of road deterioration and road user costs, it is necessary firstly to configure the software and then calibrate the individual models. The data in HDM-4 that needs to be configured to local conditions can be categorized under the following headings:

- Road Network
- Vehicle Fleet
- Road Works
- Traffic

- HDM-4 Interface Configuration

Most of the HDM-4 Interface is configured based on the analytical functionalities of Confirm and these can be reconfigured by the user. However, there are pre-defined algorithms which cannot configure.

5.3 HDM-4 Input Data Preparation

All network data stored in the RBIA are first processed and prepared in the HDM-4 Interface before they can be used in the units required for HDM-4 analysis. First, is necessary to define the road network in the appropriate manner for a given HDM-4 analysis. For HDM-4 analysis of a road network, data are required by HDM-4 for lengths of road that are homogeneous for selected characteristics of the pavement. Each homogeneous length of road is referred to as a Planning Road Section (PRS).

The aggregation and homogenization is carried out in the Confirm database prior to exporting Planning Road Sections (PRS's) of the national road network to HDM-4 for either strategy or programme analysis. Rules in the database create the PRS's by aggregating data and creating lengths that are homogenous in all the selected criteria.

The aggregation process considered the following characteristics:

- Surface Type (no aggregation across different surface types)
- Traffic Flow
- Speed Flow (number of lanes and single or dual carriageway)
- Surface Age
- Roughness
- Surface Condition

5.3.1 Derivation of Homogeneous Lengths

From the aggregated lengths, homogeneous lengths are then created. In the aggregated lengths, each characteristic has the same value but the start and end positions of the aggregated lengths for all the characteristics will not be aligned. Homogeneous lengths are created by ‘chopping’ the aggregated lengths for the different characteristics to create aligned lengths in which all characteristics are homogenous.

An example is shown in Figure5-1, illustrating the creation of the planning road sections taking into account the homogeneity it its four characteristics (surface type, traffic, carriageway width and roughness).

Distance (m) 0 1200 2750 4500 5700 7250 8000 10000 11000 12500

Surface Type	←	←	Asphalt	→	←	←	Concrete	→	→
AADT (veh/day)	←	2250	→	←	←	4500	→	←	1500
Carriageway	single	←	dual	→	→	←	single	→	→
Roughness (IRI)	←	4.0	5.5	→	7.0	4.5	6.0	→	3.5
Homogeneous Lengths	H 1	H 2	H 3	H 4	H 5	H 6	H 7	H 8	H 9

Figure 6. Creation of homogeneous lengths from aggregated lengths

The new homogeneous, amalgamated lengths are the Planning Road Sections that are transferred to HDM-4 for analysis.

5.3.2 Network States

In deriving the long term plan (i.e. for HDM-4 strategy analysis) the Philippine national road network was sub-divided into categories, resulting in a multi-dimensional Network State Matrix (NSM). Each cell of this matrix is referred to as a Network State.
The categories for strategy analysis are:

- Surface Type (3) - Asphalt, Concrete, Gravel
- Traffic Volume (5) - Very High, High, Medium, Low, Very Low
- Roughness (4) - Good, Fair, Poor, Bad
- Surface Condition (4) - Good, Fair, Poor, Bad
- Speed Flow (3+1) - 2-lane 2-directions, 2-lane 1-direction, 4-lane 2-directions (Asphalt & Concrete only)
  - Narrow 2-lane 2-directions (Gravel)

This equates to 240 (5 x 4 x 4 x 3) possible Network States for asphalt pavements, 240 for concrete pavements and 80 (5 x 4 x 4) for unsealed roads, giving a total of 560 Network States for the national road network. Representative values were assigned to the categories, as illustrated for the five traffic categories in Table 2. In this example, the representative traffic volume for asphalt surfaced roads carrying ‘Low’ volumes of traffic was 1500 vehicles per day. For the HDM-4 strategy analysis, all asphalt surfaced roads carrying between 751 and 2500 vehicles per day were assigned this representative traffic volume of 1500 vehicles per day.

Traffic Category	Asphalt		Concrete		Gravel	
	Range	Representative Value	Range	Representative Value	Range	Representative Value
Very Low	≤ 750	500	≤ 750	500	≤ 100	50
Low	751 – 2500	1500	751 – 2500	1500	101 – 200	150
Medium	2501 - 8000	5000	2501 - 8000	5000	201 – 500	350
High	8001 – 20,000	15,000	8001 – 20,000	15,000	501 – 1000	750
Very High	> 20,000	25,000	> 20,000	25,000	> 1000	1250

Table 2. Traffic categories

As described earlier, the Philippine national road network data stored in the Confirm database is aggregated to derive homogeneous PRS's. Each PRS is then assigned to a Network State. In the database, rules interpret the characteristics of each PRS to identify the cell of the NSM to which the PRS is allocated. Any value of the PRS characteristic in the range associated with the representative value of the Network State cell is sufficient to allocate a PRS to that cell.

The total length of the PRS's in each Network State is treated as a homogeneous length of road for the purposes of strategy analysis in deriving the long term plan. The representative values of each cell were assigned as the parameter values of these homogeneous lengths of road for use in strategy analysis.

Some cells of the NSM involve more than one characteristic. It is therefore likely that a value for one of the characteristics may satisfy one cell while the value of another characteristic satisfies another cell. The allocation rules in the Confirm database create a unique cell for the PRS.

The allocation rules identify how to interpret the characteristics of the cell to enable the allocation to proceed. The rules are hierarchical and the allocation proceeds until the rules are broken. In the above example, if cracking is assigned a higher status than rutting, then the PRS will be allocated to the 'Good' surface condition cell even though the rutting characteristic is 'Fair'.

5.3.3 Identifying PRS and Assigning Data

HDM-4 strategy analysis is used to derive the long term plan, whilst HDM-4 programme analysis is used to derive the multi year programme. For strategy analysis, each Network State is analyzed as a homogeneous length of road, with the representative values assigned to each cell of the NSM used as the parameter values in the analysis. For programme analysis, the individual PRS's are analyzed using the measured values of the parameters for each PRS rather than the representative values.

As stated earlier, the PRS's are assigned to specific cells of the NSM. The default values from the cell were assigned to the appropriate PRS for the parameter values not populated directly from the Confirm database. This ensured that all the parameters were populated with appropriate data for each PRS to enable an HDM-4 analysis to be carried out on the road section. In addition to the section parameters associated with each PRS, HDM-4 uses parameters for other aspects of the analysis (e.g. parameters associated with each vehicle type, maintenance cost parameters, economic parameters). Configuring and updating these values is undertaken in HDM-4.

5.4 HDM-4 Analysis

HDM-4 analysis is carried out for various purposes related to the planning and programming process for network preservation and development. Based on the objectives of the analysis, the process of data preparation may differ. The various stages in this process include:

- Determine Scope of Analysis
- Define Analysis Parameters
- Specify Long Term Plan Parameters
- Specify Multi Year Programme Parameters
- Undertake HDM-4 Analysis

In the first stage, the scope of the analysis needs to be established. It is important to determine first objective of the analysis, whether to derive a long tem plan or a multi-year works programme. Once the scope of the analysis has been established, the general analysis parameters need to be specified. This includes parameters such as the start of the analysis period, the length of the analysis period, the discount rate, the unit of currency for the analysis, etc. The road network and the vehicle fleet also need to be identified at this stage. The user can select specific sections of road and specific vehicle types for the analysis (i.e. it is not necessary to use all the road sections defined in the road network and all the vehicles types defined in the vehicle fleet).

5.4.1 Strategy Level Analysis

The steps in strategy analysis are defined as follows:

- Categorize road network into matrix cells (Network States)
- Define representative parameter values for each cell
- Define maintenance and/or improvement standards for each cell
- Specify budget constraints
- Model pavement deterioration for each matrix cell
- Calculate road user benefits
- Select maintenance/improvement standards which optimize user benefits

The initial analysis assumes an unconstrained budget to produce the unconstrained programme. The effect of various budget constraints can then be investigated to produce a series of constrained programmes for various budget levels.

5.4.2 Programme Level Analysis

The steps in carrying out Programme Analysis can be defined as follows:

- Select candidate road projects
- Determine maintenance and/or improvement options
- Specify budget limits and periods
- Produce prioritized list of projects for the budget period

As for strategy analysis, an unconstrained works programme is initially produced. Budget constraints are then applied to determine constrained works programmes.

5.5 HDM-4 Outputs

HDM-4 is used as an analytical tool to economically justify various scenarios and works programmes. It is important that the outputs of the runs of HDM-4 analyses are managed properly and verified and duly validated in the field. After generating the HDM-4 work programs, the outputs are verified in the field to check if the outputs are correct and represent the actual conditions in the field. On completion of an HDM-4 analysis, data and parameters used in the analysis, together with results from the analysis are imported to the Confirm database for viewing and presentation using the database facilities.

6.0 CONCLUSIONS

The Pavement Management System presented in this paper is currently being implemented by DPWH for the management and maintenance of the Philippine national road network. Since the start of its implementation, the DPWH management has given its full support in its institutionalization and adoption in the new planning and programming process. This has made possible the success of the system in providing the basis for prioritization of projects and optimization against performance and economic returns, thereby, minimizing external and political intervention in the prioritization and selection of road projects for inclusion in the DPWH implemented work programs. Henceforth, we can conclude that a good pavement management system that is backed-up by a reliable database and tested analytical tool like HDM-4 can allow for a more systematic selection of asset preservation projects for funding and implementation that is based on actual network needs in a country like the Philippines.

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